

S E L E C T I O N G U I D E



**INLAND
CONTROLS**

A SUBSIDIARY OF
KOLLMORGEN

HYBAND

dc

all transistor
servo power amplifiers

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HYBAND DC SERVO POWER AMPLIFIERS

Described herein is Inland Controls' complete line of high-power, solid-state, DC operational power amplifiers. The principal application for HYBAND amplifiers is the driving of DC servo motors where wideband proportional control is desired. In general, there are two classes of application which have significance in the selection of an optimum HYBAND amplifier. They are distinguished by the constancy of apparent load, as follows:

1. Where a more or less constant load impedance is presented to the driver amplifier by any low speed rate servo motor, or position servo motor with low slewing rates. The term "low speed" is generally applied when the impedance presented by the motor is fairly constant.
2. Where high slewing rates for position servos or high rates in a rate servo present a widely variable load to the amplifier. In such cases, automatic protection is needed in the amplifier for its own protection as well as for protection for the motor if its field is a permanent magnet.

INITIAL CONSIDERATIONS

This HYBAND Amplifier Selection Guide presents a variety of amplifiers at each of several output power ratings. The principal differences between the various amplifiers at similar power ratings are as follows:

1. HYBAND Amplifiers are available in either rack or modular design. The rack design in all cases includes a power supply for the amplifier, adapting it to 110 volts AC at either 60 or 400 cycles, as noted on the selection chart. Modular design in most cases involves the use of 28 volt DC power input.
2. The type of overload protection circuitry is an important distinguishing characteristic. All HYBAND Models are suitable for constant loads but only current-limited or dissipation-limited types are suitable for widely varying loads. In addition, certain models have provisions for current-limit adjustment.
3. Output stages are available in bridge and single-ended configurations.

SELECTION OF HYBAND AMPLIFIER POWER RATING

The required power rating of the amplifier is computed as the sum of the motor output power:

$$W_o = 1.36 \times T \times \omega$$

where T = torque in pound feet, ω = speed in rad/sec. plus motor winding loss:

$$W_m = (T/K_m)^2$$

where K_m = "Motor Constant" = $K_r / \sqrt{\text{ohms}}$

Note that the maximum power point might not be at the maximum speed or at the maximum torque. For sinusoidal speed variations with low system friction, for example, the maximum power point can be shown to occur at 0.707 maximum speed, at which the torque is 0.707 maximum torque. Thus, the relationship between torque and speed requirements should be known for an optimum amplifier power rating selection.

SELECTION OF AMPLIFIER FEATURES

The selection of the proper type of protection circuitry is of major importance in system performance. When used with loads with effectively constant impedance, or loads whose impedance is never less than that given for full rated output of a given amplifier, any of the HYBAND protection circuits will be satisfactory with ample protection being provided to the amplifier. However, for motor loads where armature resistance is very low (such as with high speed motors) and especially where motor plugging is involved with the further effective reduction in apparent load resistance by up to a factor of two, then a current-limited or dissipation-limited output circuit is required to protect the amplifier. These circuits limit the current under motor plugging conditions to that which will protect the amplifier. The manner in which the two limiting techniques differ may, in certain cases, be a selection criterion. An additional feature provided in some current-limited HYBAND models is a current-limit adjust which permits careful matching of the amplifier to a particular motor safe limit, or to a specified load acceleration limit.

The selection of output circuit configuration as bridge or single-ended is not important unless one side of the load must be grounded. This requirement can only be obtained by single-ended output configurations.

SELECTION OF MOTOR RESISTANCE

The proper selection of motor resistance to match the rating of the selected HYBAND amplifier is a critical though straightforward problem.

The minimum resistance possible will, of necessity, be the minimum allowable as shown on the selection guide for each amplifier (note that copper temperature resistance coefficient is 0.4%/°C). With this in mind, the available values of R_m , K_s , and K_r , are then used to calculate motor performance using the following equation:

$$\omega = (V - TR_m/K_r) / K_s$$

where ω = rad/sec, V = applied volts, T = torque, K_r = torque constant, R_m = armature resistance, K_s = motor back EMF in volt/rad/sec.

The resistance is then selected which gives best results for system performance as well as being above the minimum allowed by the amplifier selection. For further information on matching motor winding to amplifier see Appendix to Section 3 of Inland Motor's Servo Design Handbook.

After the selection of R_m , K_s , and K_r , the available current should be rechecked for suitability using the relation:

$$T = K_r I$$

HYBAND DC SERVO POWER AMPLIFIER CHARACTERISTICS

OUTPUT CHARACTERISTICS

The output ratings of HYBAND amplifiers are defined in terms of a rated output voltage, a rated output current, and a rated power output.

The rated output voltage, listed in column 3 of the selection chart, is defined as the output voltage supplied by the amplifier to any load resistance greater than, or equal to, the rated load resistance.

HYBAND DC SERVO POWER AMPLIFIER

OUTPUT CHARACTERISTICS									INPUT CHARACTERISTICS		
Model Number	Output Ratings			Load Resistance For Full Rated Power Output (ohms)	Output Configuration	Minimum Allowable Load Resistance (ohms)	Type of Overload Protection	Current Limit Adjustment Range (amps)	Number of Inputs		Load Resistance
	Watts	Volts E_m	Amps I_m						Inverting	Non-Inverting	
50A	50	22	2.5	8.8	Bridge	8	Overcurrent Trip	—	3	1	1 meg
150A	150	22	7.5	2.9	Bridge	0	Current Limit	2.5-7.5	3	1	1 meg
200B	200	25	8	3.1	Single Ended	3	Dissipation Limit ^②	—	2	0	20K
300B	300	20	15	1.33	Bridge	1	Current Limit	7.5-15	3	1	1 meg
500A	500	56	10	5.6	Bridge	5.6	Overcurrent Trip	—	2	0	50K
800A	800	85	9.5	9	Bridge	9	Overcurrent Trip	—	2	0	50K
1000A	900	65	14	4.6	Single Ended	0	Current Limit	7-20	1	1	10K
1000AR	900	65	14	4.6	Single Ended	0	Current Limit	7-20	1	1	10K
1500C	1500	75	20	3.75	Single Ended	3.75	Overcurrent Trip	—	1	1	10K
Dual ① 1000A	1800	130	14	9.3	Bridge	0	Current Limit	7-20	1	1	10K
Dual ① 1500C	3000	150	20	7.5	Bridge	7.5	Overcurrent Trip	—	1	1	10K
Column 1	2	3	4	5	6	7	8	9	10	11	12

The rated output current, listed in column 4, is the output current delivered by the amplifier into the rated load resistance at the rated output voltage.

The rated load resistance, listed in column 5, is the load for which the amplifier will deliver the rated voltage, current, and power output.

The rated power output, listed in column 2, is simply the rated voltage times the rated current delivered into the rated load resistance and is rounded off to a nominal value.

The ability of the amplifier to work with load resistance less than rated, or with active loads such as motors under decelerating or reversing conditions, depends on the particular model HYBAND amplifier chosen. Any amplifier is limited in the amount of power that can be dissipated in its output stage. Since the amplifier output stage operates from a constant supply voltage, the output stage dissipation for any given level of output current increases as the output voltage decreases. Therefore, unless the amplifier has been specifically designed for larger reserve dissipation capability, the allowable output current must be reduced as the output voltage is reduced if a safe level of dissipation is to be maintained. The minimum allowable load resistance, listed in column 7, defines the relationship of allowable output current versus output voltage.

Both single-ended and bridge output stages are used in the HYBAND amplifier line (see column 6). With a bridge output, both sides of the output are isolated above ground, and consequently both sides of the load must be isolated from ground. This is usually no problem with motor loads. With single-ended

output, one side of the output is at ground potential; consequently, one side of the load may be grounded. Load current feedback, if desired, may be easily used with single-ended output stages. Current feedback with a bridge output stage requires the use of an additional operational amplifier.

All HYBAND Amplifiers are protected against damage due to short circuits on the output, and most are protected against damage due to overload over a wide variety of loading conditions (see column 8). Three types of protection are used: 1) overcurrent trip, 2) current-limiting, and 3) power dissipation limiting. In addition, most HYBAND Amplifiers contain thermostats which disconnect the amplifier if the heat sink temperature becomes excessively high. The type of protection used determines the ability of the amplifier to work with low resistance or active loads.

For motor loads where the motor back EMF is significant, and where full acceleration and/or output torque capability must be maintained over the entire operating speed range, current-limited amplifiers should be chosen. In this way, full load current, which means full torque, will be available over the entire motor speed range. In addition, by limiting the motor current, possible demagnetization of a motor PM field due to excessive armature current is avoided.

If full torque is not required at all speeds, amplifiers with power dissipation limiting can be used. Full torque output is available at, or close to, maximum speed and reduced torque is available at stall and under reversing conditions.

In HYBAND Amplifiers with overcurrent trip, a special circuit

R CHARACTERISTICS

Output Stage Type	TRANSFER CHARACTERISTICS				POWER REQUIREMENTS		
	Voltage Gain (v/v)	Small Signal Frequency Response (kc)	Gain Band- Width Product (x 10 ³)	Provisions for Servo- Compensa- tion Networks	Volts	Fre- quency (cps)	Con- struction
> 5 meg	Adj. from 10-0.5 x 10 ⁶	10 @ 10V/V ^③	40 ^④	Yes	28	DC	Modular
> 5 meg	Adj. from 10-0.5 x 10 ⁶	10 @ 10V/V ^③	40 ^④	Yes	28	DC	Modular
—	Adj. from 10-20 x 10 ³	10 @ 10V/V	100	Yes	115	50-400	Rack
> 5 meg	Adj. from 10-0.5 x 10 ⁶	10 @ 10V/V ^③	40 ^④	Yes	28	DC	Modular
—	Adj. from 10-200	10 @ 10V/V	100	No	115	60 ^⑤	Rack
—	Adj. from 10-200	10 @ 10V/V	100	No	115	60 ^⑤	Rack
10K	10	25	250	No	±70	DC	Modular
10K	10	25	250	No	115	60 ^⑤	Rack
10K	10	25	250	No	±80	DC	Modular
10K	10	25	250	No	—	—	Rack or Modular
10K	10	25	250	No	—	—	Rack or Modular
13	14	15	16	17	18	19	20

① The Dual 1000A and the Dual 1500C consist of two HYBAND 1000A amplifier in series and two HYBAND 1500C amplifiers in series respectively.

② Current limiting in the HYBAND Model 200B dissipation limited amplifier varies from 2 amps at 0 volts output to 8 amps at 25 volts output.

③ Frequency response of power stage.

④ Gain bandwidth product of preamplifier only.

⑤ 400 cps available on special order.

continuously monitors the amplifier output current and shuts down the amplifier within a few microseconds if rated current is exceeded. Since only output current is monitored, and not power stage dissipation, amplifiers using this protective scheme may be used only with load resistances larger than the rated load resistance.

Current-limited HYBAND Amplifiers will put out rated current at any output voltage. The current limit is adjustable over a wide range (see column 9) and may be used to protect output loads such as torque motors from damage due to overcurrent. The amplifiers have output stages with large excess dissipation capacity to enable them to withstand the power dissipation that arises when supplying full output current at any output voltage.

INPUT CHARACTERISTICS

Column 10 lists the number of inputs to the amplifier. For amplifiers with single ended output stages, the output will be 180 degrees out of phase with the inverting inputs, and in phase with the noninverting inputs. For amplifiers with bridge output stages, the terms refer to which side of the differential input amplifier the input is connected.

The signals presented to all the inputs are summed algebraically, and the amplifier output voltage will be equal to the amplifier gain times the sum of the input voltages.

TRANSFER CHARACTERISTICS

All HYBAND Amplifiers offer voltage gain as well as power gain, and have a frequency response far in excess of that required

for servo systems. Most units have provision for wide range gain adjustment (see column 14), and for frequency-shaping for servo compensation (see column 17). The frequency response stated in column 15 defines the frequency at which the gain is down three decibels and/or the phase shift is 45 degrees for small signal inputs. For amplifiers with adjustable gain, the bandwidth will decrease with increasing gain so that the gain bandwidth product, listed in column 16, remains constant. The internal compensation of any of the amplifiers can be factory modified on special order to provide the full bandwidth for high gain settings.

MIL SPECS

Inland Controls, Inc., has conducted and is continuing to conduct environmental tests on its modular amplifiers. An engineering report is available, summarizing the results of these tests. In addition, amplifiers designed to meet MIL-E-16400E and MIL-E-5400H are available on special order.

For details consult the factory.

HYBAND

DC SERVO POWER AMPLIFIERS

HYBAND 50A MODULAR AMPLIFIER

- Integral preamplifier
- Adjustable open loop gain to 0.5×10^6 V/V
- Multiple summing points
- Provision for servo compensation networks
- Short circuit protected
- Operation from single 28 volt supply
- All solid state silicon transistor design
- Low drift — less than 10 microvolts/°C



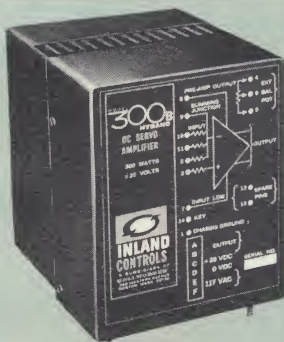
HYBAND 150A MODULAR AMPLIFIER

- Integral preamplifier
- Adjustable open loop gain to 0.5×10^6 V/V
- Multiple summing points
- Provision for servo compensation networks
- Current limiting adjust from ± 2.5 to ± 7.5 amps
- Short circuit protected
- Operation from single 28 volt supply
- All solid state silicon transistor design
- Low drift — less than 10 microvolts/°C



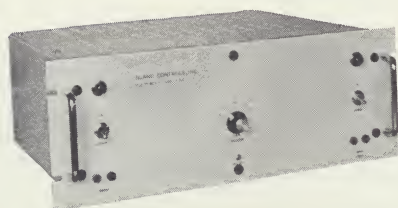
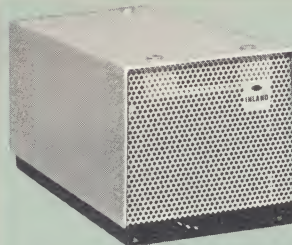
HYBAND 300B MODULAR AMPLIFIER

- Integral preamplifier
- Adjustable open loop gain to 0.5×10^6 V/V
- Multiple summing inputs
- Provision for servo compensation networks
- Current limiting adjust from ± 7.5 to ± 15 amps
- All solid state silicon transistor design
- Low drift — less than 10 microvolts/°C



HYBAND 1000A MODULAR AMPLIFIER

- Adjustable current limiting
- Short circuit protected
- Wideband frequency response
- Linear operation — No switching
- Input matched to standard operational amplifiers
- All silicon transistor design
- Modular construction
- Light weight and compact size



HYBAND 200B AMPLIFIER

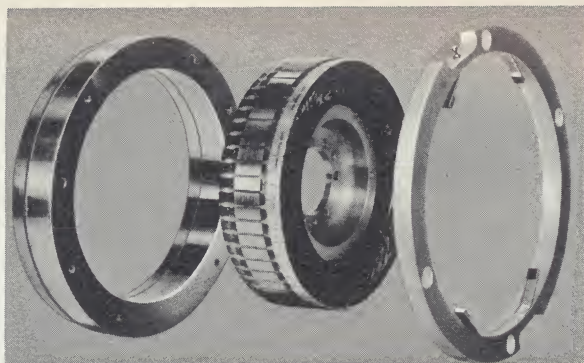
- All solid state circuitry
- Self-contained power supply and preamplifier
- Direct operation from AC line power
- Provisions for operational input
- Current limiting output circuitry
- Linear operation
- Wide bandwidth — up to 10 KC
- Low drift — $100 \mu\text{V}/^\circ\text{C}$
- High open loop gain — 20,000 V/V



HYBAND 500A and HYBAND 800A AMPLIFIERS

- All solid state circuitry
- Self-contained power supply and preamplifier
- Direct operation from AC line power
- High input impedance — 50 K ohms
- Wide bandwidth — up to 10 KC
- Linear operation — No switching
- High power output — up to 800 watts

DIRECT DRIVE TORQUE MOTOR DATA



A Direct Drive Torque Motor is an actuator for a servo system. Inland Motor* and Inland Controls design and offer the most complete line of matched components for complete servo systems. Literature and technical data are available on all components.

MOTOR SELECTION GUIDE

INLAND MOTOR TYPE	PEAK TORQUE @ STALL		CONTINUOUS WATT @ STALL		NO LOAD SPEED rad/sec	DAMPING FACTOR lb-ft/rad/sec	ELECTRICAL TIME CONSTANT milliseconds	FRICTION lb-ft	ROTOR INERTIA lb-ft-sec ²	MAX SHAFT POWER WATTS	MAX POWER RATE lb-ft/sec ²	MOTOR CONSTANT lb-ft/√watt	TYPICAL DIMENSIONS			WEIGHT
	lb-ft	Watts @ 25°C	Watts	lb-ft @ 25°C									O.D.	I.D.	THICKNESS	
Symbol	T _p	I _{PR}	I _{SR}	T _C	ω _{NL}	F _D	T _E	T _f	J _M	P _S	P	K _M	inches	inches	inches	oz or lb
T-0709	0.034	60	2.4	0.007	1300	2.6 x 10 ⁻⁵	260	1 x 10 ⁻³	5.7 x 10 ⁻⁷	15	2031	4.4 x 10 ⁻³	1.12	0.18	0.56	1.6 oz
T-1218	0.078	63	6.8	0.026	580	1.3 x 10 ⁻⁴	0.40	2.6 x 10 ⁻³	3.1 x 10 ⁻⁶	15	1979	9.9 x 10 ⁻³	1.50	0.62	0.51	2.3 oz
T-1352	0.104	60	5.1	0.03	400	2.6 x 10 ⁻⁴	0.30	3.6 x 10 ⁻³	4.2 x 10 ⁻⁶	14	2396	0.014	1.93	0.62	0.50	4.3 oz
T-1342	0.210	98	6.0	0.05	340	6.2 x 10 ⁻⁴	0.34	5.2 x 10 ⁻³	8.3 x 10 ⁻⁶	26	5208	0.021	1.93	0.62	0.84	7.6 oz
NT-1319	0.125	64	5.1	0.04	370	3.4 x 10 ⁻⁴	0.29	4.2 x 10 ⁻³	4.6 x 10 ⁻⁶	16	3385	0.016	1.93	0.62	0.50	4.3 oz
T-1911	0.31	60	8.0	0.11	143	2.2 x 10 ⁻³	0.40	0.013	4.6 x 10 ⁻⁵	15	2135	0.040	2.34	1.25	0.86	9.5 oz
T-2157	0.18	41	8.9	0.08	160	1.1 x 10 ⁻³	0.60	0.057	3.2 x 10 ⁻⁵	10	1042	0.028	2.81	1.00	0.62	8.8 oz
T-2170	0.31	32	11.8	0.18	75	4.2 x 10 ⁻³	1.0	7.8 x 10 ⁻³	5.7 x 10 ⁻⁵	8	1719	0.055	2.81	1.00	1.00	13.8 oz
T-2171	0.63	50	14.8	0.34	57	0.012	1.5	0.016	9.9 x 10 ⁻⁵	12	3958	0.089	2.81	1.00	1.50	25 oz
T-2509	0.16	48	8.9	0.07	220	6.8 x 10 ⁻⁴	0.25	0.052	3.1 x 10 ⁻⁵	12	781	0.022	3.00	1.75	0.37	4.5 oz
T-2604*	0.31	140	24.5	0.13	327	9.4 x 10 ⁻⁴	2.0	0.013	7.8 x 10 ⁻⁵	34	1250	0.027	3.18	2.00	0.47	5.6 oz
T-2804	0.16	67	10.1	0.61	320	4.9 x 10 ⁻⁴	0.30	7.8 x 10 ⁻³	4.5 x 10 ⁻⁵	17	573	0.019	3.38	2.25	0.40	5.1 oz
T-2967	0.52	67.5	14.3	0.24	97	5.4 x 10 ⁻³	1.2	0.010	1.8 x 10 ⁻⁴	17	1510	0.064	3.73	1.64	0.89	1.1 lb
T-2955	0.85	77	16	0.39	67	0.013	1.6	0.013	2.3 x 10 ⁻⁴	19	3100	0.097	3.73	1.64	1.09	1.5 lb
T-2950	1.20	79	18.6	0.58	48	0.025	2.1	0.017	2.9 x 10 ⁻⁴	20	5000	0.135	3.73	1.64	1.34	2.15 lb
T-3203	1.0	87	23.5	0.53	63	0.016	2.3	0.020	3.5 x 10 ⁻⁴	21	2880	0.11	4.09	2.00	1.09	1.6 lb
T-3910	0.52	11.5	11.5	0.52	16	0.033	1.0	0.042	3.4 x 10 ⁻⁴	3	781	0.16	4.56	2.94	0.69	1.1 lb
T-4036	1.8	91	24.2	0.94	37	0.049	2.0	0.035	8.7 x 10 ⁻⁴	23	3700	0.19	5.12	2.39	1.25	2.9 lb
T-4436	1.0	70	32.5	0.68	51	0.020	0.70	0.030	5.5 x 10 ⁻⁴	17	1820	0.12	5.12	3.50	0.65	1.2 lb
T-4424	1.1	49	32.5	0.91	33	0.034	0.51	0.030	5.5 x 10 ⁻⁴	12	2200	0.16	5.12	3.50	0.65	1.19 lb
T-4601	0.8	210	26.5	0.28	190	4.4 x 10 ⁻³	0.25	0.025	0.048	52	1330	0.055	5.12	4.00	0.58	0.83 lb
T-5003*	6.0	450	44.8	1.9	55	0.113	0.83	0.12	3.8 x 10 ⁻³	112	9470	0.28	6.00	3.50	1.50	5.7 lb
T-5134	2.7	85	34.8	1.7	22	0.12	2.5	0.050	2.4 x 10 ⁻³	20	4900	0.29	6.25	2.39	1.31	4.8 lb
T-5135	4.0	119	38.1	2.3	22	0.18	3.5	0.070	3.2 x 10 ⁻³	30	5000	0.37	6.25	2.39	1.56	6.4 lb
T-5403	1.3	118	17	0.49	65	0.020	0.5	0.040	8.6 x 10 ⁻⁴	29	1970	0.12	6.12	4.50	0.67	1.15 lb
T-5503*	0.83	81	25	0.47	72	0.012	0.77	0.029	1.5 x 10 ⁻³	20	474	0.093	6.50	4.72	0.63	1.2 lb
T-5730	7.0	260	40	2.7	27	0.26	2.7	0.070	5 x 10 ⁻³	64	9600	0.43	7.20	3.95	1.62	7.25 lb
T-7202	11	325	66.7	5.0	22	0.5	3.15	0.10	0.010	82	12 x 10 ³	0.61	9.00	5.38	1.62	10.3 lb
T-7203	22	525	72.7	8.5	16	1.26	5.0	0.20	0.019	119	25 x 10 ³	1.0	9.00	5.16	2.56	18.3 lb
T-10036	35	774	190	17.4	16	2.3	3.0	0.37	0.060	190	20 x 10 ³	1.26	13.69	3.50	3.62	52.5 lb
T-10035	100	1046	267	50.6	7.7	13	6.0	1.0	0.18	261	56 x 10 ³	3.1	13.31	3.38	5.31	95.5 lb
T-12008	200	2600	400	78	9.3	21.6	8.5	1.0	0.5	630	80 x 10 ³	3.9	19.00	6.00	7.50	194 lb
T-18002	300	1450	615	195	3.6	83.9	20	3.0	1.4	366	64 x 10 ³	7.88	26.62	10.35	5.69	300 lb
T-18004	900	3500	667	392	2.8	320	25	4.0	3.1	854	2.6 x 10 ⁵	15.2	26.50	9.38	10.56	650 lb
T-36001	3000	7350	2000	1565	1.8	1660	22	12	26	1831	3.5 x 10 ⁵	35	45.00	25.68	10.25	1360 lb

*Inverted Torquer



HYBAND Amplifiers have been designed with a particular objective of driving dc torque motors manufactured by Inland Motor Corp. To help select the required amplifier ratings, the table above is reproduced from the Inland Motor Selection Guide, covering the standard torque motors offered.

*Also a subsidiary of Kollmorgen.

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